ARI Research Note 88-32

DEVELOPMENT OF AIMING RULES FOR THE 25-MM GUN OF THE BRADLEY FIGHTING VEHICLE

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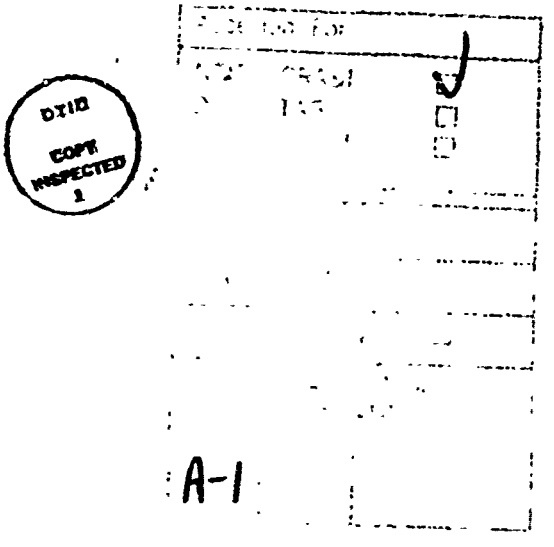

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This research note describes the development of aiming rules to optimize the first-round accuracy of the 25-mm gun when it is used to engage moving vehicles from a stationary Bradley Fighting Vehicle (lead rule, and to engage stationary targets from a moving vehicle (reverse-lead rule). Selection of rules was based on predicted target hit capabilities, and ease of use and training. Rules were expressed as simple words which described the relationship of the target to the sight reticle. Developing aiming rules will replace previous rules presented in the Bradley Fighting Vehicle Gunnery Field Manual, FM 23-1.

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FOREWORD

Since 1975 the Army Research Institute (ARI) has contributed to a program to define emerging problems and address critical issues affecting the Bradley Fighting Vehicle (BFV). Consistent with that program, this report describes the development of improved aiming rules for engaging moving targets and for firing on the move with the 25-mm gun. The Discussion and Conclusions and Summary sections are intended for gunnery literature developers for the BFV. However, the technically based Procedure and Findings sections of the report are intended for a scientific audience.

ARI's Fort Benning Field Unit, a division of the Training Research Laboratory, monitored the research reported here. ARI's mission is to conduct research of training and training technology using infantry combat systems and problems as mediums. The research task which supports this mission is titled Advanced Methods and Systems for Fighting Vehicle Training and is organized under the "Train the Force" program area. Sponsorship for this research effort is provided by a Memorandum of Understanding (effective 31 May 1983) between the U.S. Army Infantry School (USAIS), TRADOC, Training Technology Agency and ARI, which established how joint efforts to improve BFV tactical doctrine, unit, and gunnery training would proceed.

As a result of close cooperation and coordination with the BFV gunnery proponent of USAIS, the developed aiming rules will be integrated into the BFV Gunnery field manual (FM 23-1).

DEVELOPMENT OF AIMING RULES FOR THE 25-MM GUN OF THE BRADLEY FIGHTING VEHICLE

EXECUTIVE SUMMARY

Requirement:

To develop aiming rules that optimize first-round accuracy for the 25-mm gun of the Bradley Fighting Vehicle (BFV) during engagement of moving vehicular targets from a stationary BFV (lead rule) and while firing on the move at a stationary target (reverse-lead rule).

Procedure:

The amount of lead was calculated for targets at different ranges, traveling at varied speeds, and approaching at different angles when engaged with armor-piercing (AP) and high-explosive (HE) ammunition. Candidate aiming rules were selected based on this analysis, and predicted target hit capabilities were determined for the rules. Reverse-lead requirements for AP and HE ammunition were calculated for a BFV moving at varied speeds with the gun oriented at varied angles relative to direction of movement.

Findings:

Selection of the optimal aiming rules was based on predicted target hit capabilities, anticipated ease of use and training, and reticle design. The optimal lead rule for engaging moving targets with AP ammunition is 5 mils from target center-of-mass; this rule provides a high probability of target hits up to the tracer-burnout range. The AP lead rule is called GAP LEAD because the target is centered in the gap of the lead lines on the reticle. The optimal HE lead rule is 8.75 mils from target center of mass. The rule is called FAR LEAD because the furthest lead line is centered on the target. The hit capability of the HE lead rule is affected more by target range than the AP lead rule. When the BFV is firing over its flank on the move at a stationary target, a 5 mil reverse-lead rule will provide high hit potential for AP and HE ammunition.

Utilization of Findings:

If other gunner and equipment errors are minimal, application of the developed aiming rules should allow a high probability of first-round target hits and near misses with the 25-mm gun during engagement of moving targets from a stationary BFV and when firing at stationary targets while moving. The developed AP lead, HE lead, and reverse-lead rules will replace currently recommended aiming rules in the BFV Gunnery field manual (FM 23-1).

DEVELOPMENT OF AIMING RULES FOR THE 25-MM GUN OF THE BRADLEY FIGHTING VEHICLE

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Background

The 25-mm automatic gun of the Bradley Fighting Vehicle (BFV) often is referred to as a burst-on-target weapon system not designed to achieve first-round hits. However, when armor-piercing (AP) ammunition is used against a BMP-sized target (about 2 meters high), the materiel need statement requires the 25-mm weapon system to have a high first-round hit capability from 0 through 1400 meters when a range control setting of 1200 meters is used (Department of the Army, 1978).

If the gunner or commander is to achieve first-round hits against moving targets, the aiming point must be offset from target center of mass. Lead rules are used to engage vehicular targets (e.g., a BMP) that are moving perpendicular (or nearly so) to the line of fire. When AP ammunition is used, the Test version of the BFV Gunnery field manual (FM 23-1, 1983) recommended that the center dot of the reticle be placed on the front or leading edge of the target. A latter version of the manual (FM 23-1, 1986) recommended a 2.5-mil lead from target center of mass. A 5-mil lead is recommended when HE ammunition is used against thin-skinned vehicles like trucks and BRDMs.

When a moving BFV fires over its flank at a stationary target, the gunner must apply reverse lead or aim behind target center-of-mass relative to direction of movement. The gunnery manual (FM 23-1, 1983; 1986) recommends aiming at the "far" edge of the target.

Problems

Observations of gunnery performance at Fort Benning indicated that training rounds typically hit behind moving vehicular targets. This may be caused by either failure to apply the recommended lead rule or ballistic differences between training and service (i.e., AP) ammunition. It also is possible that the recommended aiming rule does not apply enough lead on the target.

Observation of gunnery training at Fort Benning has not revealed inadequate reverse lead; however, speeds of the BFV during training (5 to 10 miles/hr) may be slower than in a combat environment. Because the amount of aiming point adjustment is directly related to speed of the firing vehicle, it is possible that the recommended reverse-lead rule would be insufficient for faster BFV speeds.

Purpose

The research objective was to develop/modify aiming rules that optimize first-round hit capabilities for both AP and HE ammunition (a) when firing at moving targets from a stationary BFV (lead rules) and (b) when firing over the flank of the BFV at a stationary target (reverse-lead rules).

Lead Requirements Analysis

Background

Mathematical analysis was conducted to determine the amount of lead required to hit a moving target from a stationary BFV. The amount of required lead depends on target speed, target range, angle of approach by the target, and flight time of the round. Faster targets require more lead than slower ones, targets moving perpendicular to the BFV require lead whereas a target moving straight at a BFV does not, and more lead is required for longer range than shorter range targets. Lead requirements will be greater for the HE round compared to AP ammunition because the HE round is slower and losses speed more quickly.

Procedure

The mathematical analysis determined lead requirements under a wide range of target speeds, ranges, and angles of approach when engaged with AP and HE ammunition. Range varied from 200 to 3000 meters at 200-meter intervals. Target speeds ranged from 8 to 48 km/hr at 8 km/hr intervals, but after examination of the data, it was decided that development of lead rules would be based on the predicted speed of 20 miles/hour (32 km/hr) for a threat vehicular target (FM 23-1, 1983). Target angles of approach for the analysis ranged from 10 to 90 degrees at 10-degree intervals.

The mathematical model for computing lead requirements is presented in Figure 1. The target range was the distance between the BFV and point of impact. Flight time for that range was obtained from the firing tables (FT 25-A-1, 1984). The following equations were used to calculate lead requirements in mils.

distance traveled = target speed (km/hr) X flight time (sec) (1)

lateral motion = sin (target angle) X distance traveled (2)

lead angle (mils) = arcsin (lateral distance / target range) (3)

Findings

Figure 2 presents the amount of required lead for AP and HE ammunition for a target traveling 32 km/hr at ranges of 1000, 1600, 2200, and 2800 meters. Lead is expressed in mils because reticles are marked in mils. For AP ammunition, lead requirements increase slightly as range increases, whereas target angle has a dramatic effect on lead requirements. For example, at a range of 1600 meters, the AP lead requirement is about 7.5 mils while a 5-mil lead is required for a target approaching at a 45-degree angle.

Lead requirements for HE ammunition also vary dramatically with target angle. But in contrast to AP ammunition, target range has a noticeable impact on lead requirements. Lead requirement for HE ammunition at 2800 meters (21 mils) is nearly twice that required at 1000 meters (10.9 mils). In comparing

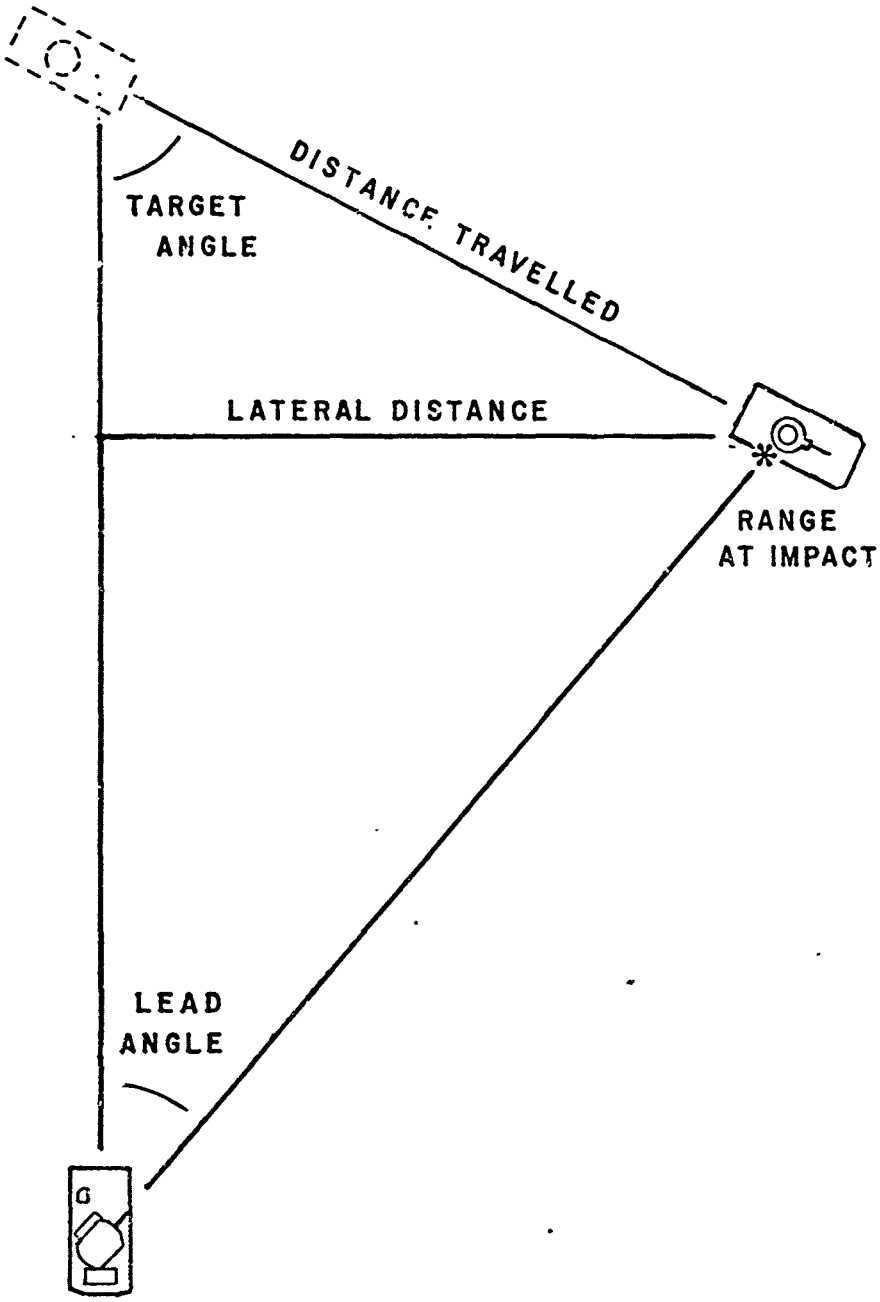

Figure 1. Mathematical model for determining lead requirements.

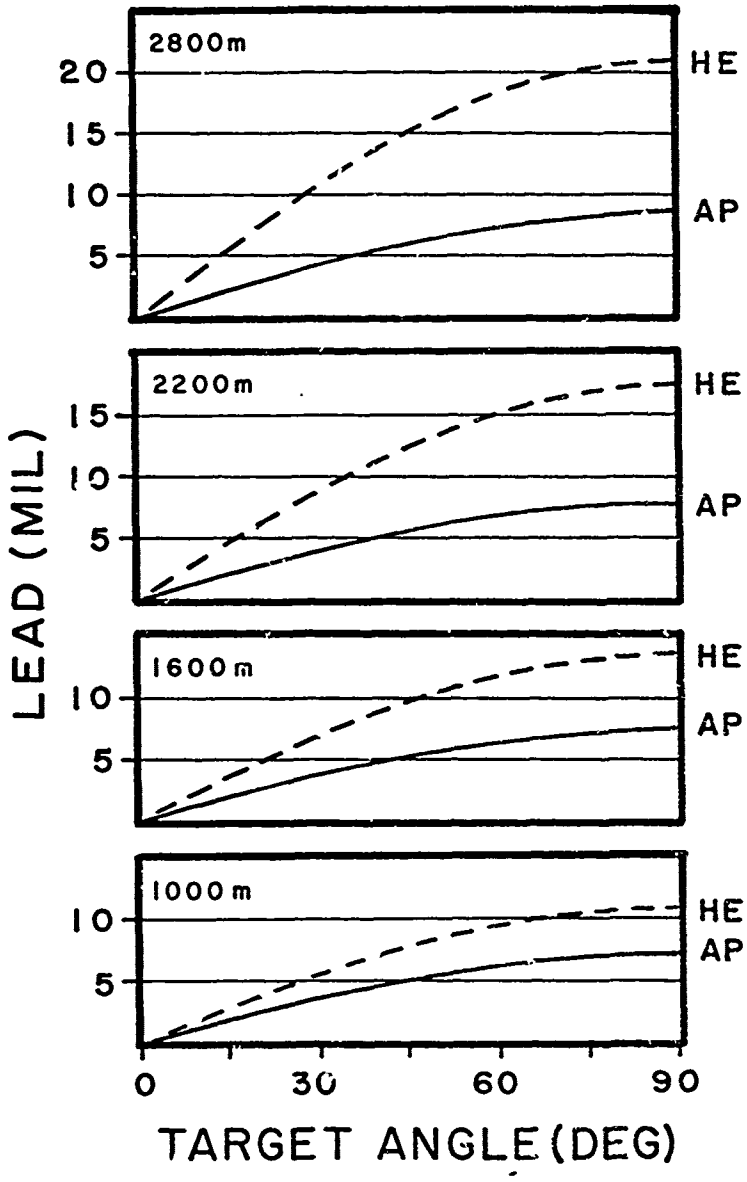

Figure 2. Lead requirements for AP and HE ammunition fired at a target traveling 32 km/hr at varied ranges and angles of approach.

the lead requirements of HE and AP ammunition, the HE lead requirement is about twice that of AP at target ranges between 1600 to 2200 meters and the difference becomes even greater beyond 2200 meters.

Target range affects lead requirements for HE ammunition more than for AP ammunition because HE ammunition loses velocity more quickly after the projectile leaves the barrel. This can be illustrated at a target range of 2200 meters where the remaining velocity for AP ammunition is 72 percent of the muzzle velocity while the velocity for HE ammunition is only 26 percent of the initial velocity of the round.

Predicted Hit and Miss Capabilities of Selected Lead Rules

Background

Lead is applied when the target is moving perpendicular relative to the line of fire (i.e., the target has its side or flank oriented to the gun). No lead is applied when the target is approaching the BFV, however, the gunnery manual provides no guidance on aiming rules for oblique target angles. To eliminate the need for a separate aiming rule for oblique targets, ARI developed a technique to classify all target angles as either frontal or flank. As illustrated in Figure 3, target angle is determined by comparing how much of the front and side of the vehicle that is seen. A target is a frontal view if its front looks larger than the side. For a flank view, the side looks larger than the front. When this technique is used, a flank view of a target is oriented at an angle greater than 25 degrees (Perkins, 1987).

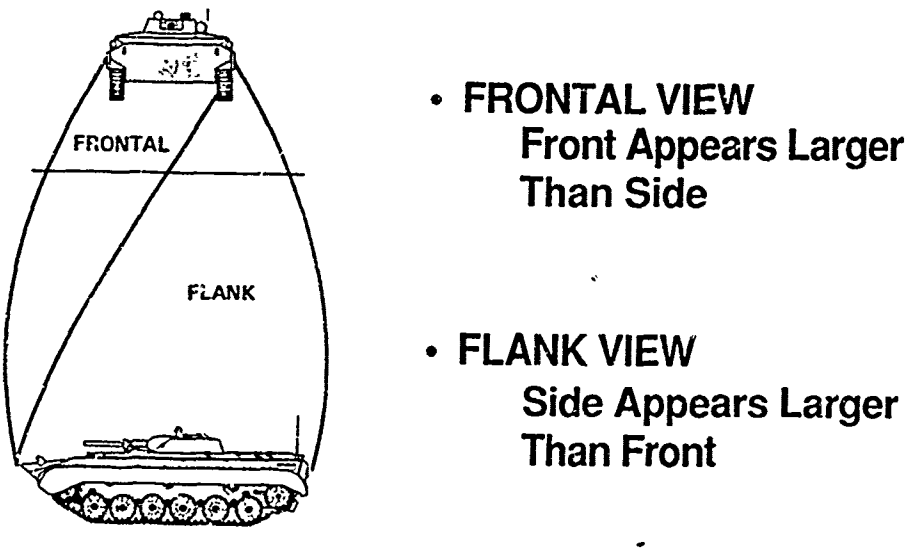

Figure 3. Classification of target angle.

Candidate lead rules were developed based on the lead-requirement analysis and the capability of the integrated sight unit (ISU) gun reticle (see Figure 4) to support the rules. Predicted hit capabilities of candidate lead rules were calculated with attempts to determine if effective AP and HE lead rules could be developed for flank views (25 degrees and greater) of moving targets. Following this, selection of the optimal lead rules for AP and HE ammunition was based on predicted target hit capabilities, considerations based on ease of training, and the capability of the soldier to recall and apply lead rules in a combat environment.

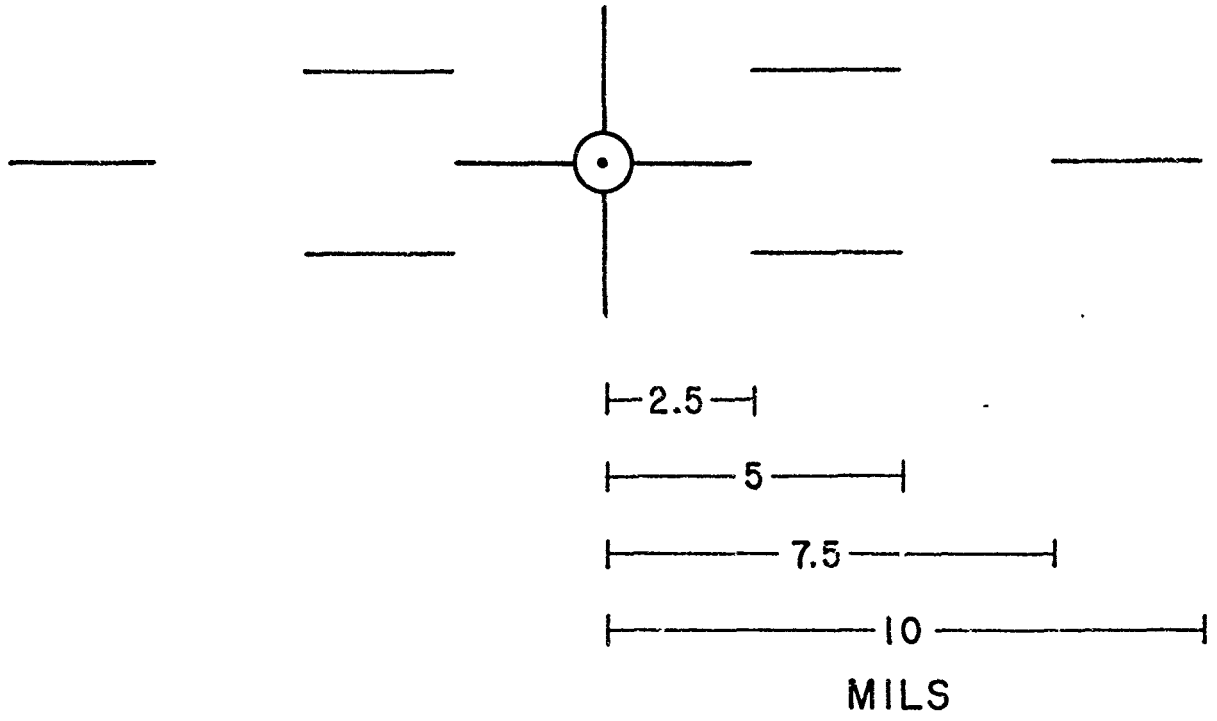

Figure 4. Illustration of the ISU gun reticle and distance in mils of lead lines from the center dot.

Procedure

Analysis included target ranges, angles, and speeds used in the previous analysis. Calculation of predicted target hits and misses for AP ammunition was based on engagement of a BMP-sized target (6.74 meters long by 2.94 meters wide) A BRDM-sized target (length = 6.5 meters, width = 2.2 meters) was used in the analysis for HE ammunition. The total exposed width of a target varies with target angle. The exposed width of the target was calculated as described in another report (Perkins, 1987) for oblique angles of orientation (i.e., angles from 10 through 80 degrees) for both the AP and HE analysis.

There typically are two points of reference for application of a lead rule: (a) target center-of-mass and (b) the front or leading edge of the target. The analysis examined the effects of the following seven aiming rules on target hit and miss capability with AP ammunition:

(a) Center-of-mass (i.e., no lead);

(b) Front-edge;

(c) 2.5 mils from center-of-mass;

(d) 2.5 mils from front-edge;

(e) 5 mils from center-of-mass;

(f) 5 mils from front-edge;

(g) 7.5 mils from center-of-mass.

The last five aiming points were the most likely candidates for the optimal lead rule; aiming points (c) and (d) are or were taught by USAIS during gunnery instruction and aiming points (e), (f), and (g) were developed after the lead requirement analysis.

The following seven aiming points were analyzed for hit capability with HE ammunition;

(a) Center-of-mass;

(b) Front-edge;

(c) 5 mils from center-of-mass;

(d) 7.5 mils from front-edge;

(e) 7.5 mils from center-of-mass;

(f) 3.75 mils from center-of-mass;

(g) 10 mils from center-of-mass.

Rule (c) is the currently recommended HE lead rule (FM 23-1, 1986). Aiming points (d) through (g) were developed based on the lead requirement analysis. In general, the amount of lead for candidate aiming points for HE ammunition was larger than for AP because of the greater lead requirement for HE ammunition. The comparison of hit capabilities of the various aiming points will be separately discussed for AP and HE ammunition.

The hit capabilities of various aiming-points against flank views of moving targets were calculated for target ranges through 2800 meters; however, data will be presented at 400-meter intervals up to a maximum range of 1600 meters. Tracer burnout for AP ammunition is 1700 meters so effective target engagement is unlikely past this range. For HE ammunition, more than 10 mils lead is required beyond 1600 meters. The ISU gun reticle has markings extending only up to 10 mils from the center dot so it is not possible to accurately apply a lead beyond this point on the reticle.

Findings

AP ammunition. Table 1 presents predicted hits and misses for the seven aiming points. A zero score indicates a hit anywhere on the target, a negative score predicts projectile impact behind the target while a positive score indicates round impact in front of the target (i.e., too much lead applied). The last five aiming points of Table 1 were the primary candidates

Table 1

Predicted Amount of Miss (mils) with AP Ammunition for a BMP Traveling 32 km/hr

Lead (mil)	Aimpoint reference	Range (m)	Target angle (degrees) 10	20	30	40	50	60	70	80	90
0	Center of mass	400	0	0	0	0	0	0	0	0	0
		800	0	0	0	-0.2	-0.7	-1.2	-1.7	-2.1	-2.5
		1200	0	-0.4	-1.3	-2.1	-2.8	-3.4	-4.0	-4.4	-4.7
		1600	0	-0.9	-1.8	-2.6	-3.4	-4.0	-4.6	-5.0	-5.2
0	Front edge	400	0	0	0	0	0	0	0	0	0
		800	0	0	0	0	0	0	0	0	0
		1200	0	0	0	0	0	-0.3	-0.9	-1.4	-1.8
		1600	0	0	0	-0.5	-1.1	-1.7	-2.2	-2.7	-3.1
2.5	Center of mass	400	0	0	0	0	0	0	0	0	0
		800	0	0	0	0	0	0	0	0	0
		1200	0	0	0	0	-0.3	-0.9	-1.5	-1.9	-2.2
		1600	0	0	0	-0.1	-0.9	-1.5	-2.1	-2.5	-2.7
2.5	Front edge	400	1.3	0.2	0	0	0	0	0	0	0
		800	1.2	0	0	0	0	0	0	0	0
		1200	1.2	0	0	0	0	0	0	0	0
		1600	1.2	0	0	0	0	0	0	-0.2	-0.2
5.0	Center of mass	400	0	0	0	0	0	0	0	0	0
		800	1.2	0	0	0	0	0	0	0	0
		1200	2.0	0.3	0	0	0	0	0	0	0
		1600	2.4	0.9	0	0	0	0	0	0	0
5.0	Front edge	400	3.8	2.7	1.6	0.6	0	0	0	0	0
		800	3.8	2.7	1.6	0.6	0	0	0	0	0
		1200	3.7	2.4	1.2	0.2	0	0	0	0	0
		1600	3.7	2.5	1.3	0.3	0	0	0	0	0
7.5	Center of mass	400	1.1	0	0	0	0	0	0	0	0
		800	3.7	2.0	0.3	0	0	0	0	0	0
		1200	4.5	2.8	1.2	0	0	0	0	0	0
		1600	4.9	3.4	1.9	0.7	0	0	0	0	0

for lead rules to be used for engaging flank views (30 to 90 degree target angles) of moving targets.

The effectiveness of the selected aiming points on flank views varied with target range and angle. The aiming rule of 5 mils from center-of-mass led to predicted hits for flank angles at all examined target ranges. Slightly less effective was an aiming point of 2.5 mils from target front-edge; target misses began to occur at the the most extreme flank angles (80 and 90 degrees) at 1600 meters. When compared to aiming points of 5 mils from center-of-mass and 2.5 mils from front-edge, other aiming points had less effective hit capabilities.

HE ammunition. Table 2 presents hit capabilities for the selected aiming points. The last five rules listed in the table were the primary candidates. The least effective of these rules was 5 mils from target center-of-mass. The most effective rules were 7.5 mils from center-of-mass, 7.5 mils from the front edge, 8.75 mils from center-of-mass, and 10 mils from center-of-mass. Minor differences in the hit capabilities of these rules depended on target range and angle.

Reverse-Lead Requirement Analysis

Background

Reverse-lead requirements are affected by muzzle velocity of the ammunition, the speed of the BFV, and the orientation of the gun relative to direction of BFV movement. For a given vehicle speed and muzzle velocity, the amount of reverse-lead is greatest when the barrel is pointed straight to the side. Less reverse-lead is required as the barrel is pointed either to the front or rear of the vehicle. Target range does not affect reverse-lead requirements if they are expressed in mils (i.e., an angular measurement).

Procedure

Reverse-lead requirements were determined for AP and HE ammunition for vehicle speeds ranging from 8 to 48 km/hr at 8-km/hr intervals and gun barrel angles of 10 through 90 degrees at 10-degree intervals. The gun barrel is facing in the direction of BFV movement for a 0-degree angle while the barrel is facing perpendicular to vehicle movement for 90-degree angles. Muzzle velocities used in the analysis were 1345 and 1100 meters/second for AP and HE ammunition, respectively (FT 25-A-1, 1984).

Figure 5 illustrates the mathematical model used to calculate reverse-lead. The following steps were used to calculate the lead angle.

$$y1 = [\sin (90 \text{ degrees} - \text{lead angle})] \times [\text{muzzle velocity}] \quad (1)$$

$$y2 = y + \text{BFV speed} \quad (2)$$

$$x = y1 \times \cot (90 \text{ degrees} - \text{gun angle}) \quad (3)$$

Table 2

Predicted Amount of Miss (mils) with HE Ammunition for a BRDM Target Traveling at 32 km/hr

Lead (mil)	Aimpoint reference	Range (m)	Target angle (degrees) 10	20	30	40	50	60	70	80	90
0	Center of mass	400	0	0	0	0	0	0	0	-0.3	-0.8
		800	0	-0.8	-1.8	-2.8	-3.7	-4.5	-5.2	-5.7	-6.0
		1200	-0.7	-2.3	-3.8	-5.3	-6.5	-7.6	-8.4	-9.0	-9.3
		1600	-1.3	-3.3	-5.1	-6.9	-8.4	-9.6	-10.6	-11.2	-11.5
0	Front edge	400	0	0	0	0	0	0	0	0	0
		800	0	0	0	0	0	-0.3	-0.8	-1.4	-1.9
		1200	0	-0.5	-1.7	-2.8	-3.8	-4.7	-5.5	-6.1	-6.6
		1600	-0.3	-1.9	-3.5	-5.0	-6.3	-7.5	-8.4	-9.1	-9.4
5.0	Center of mass	400	0	0	0	0	0	0	0	0	0
		800	1.1	0	0	0	0	0	-0.2	-0.7	-1.0
		1200	1.5	0	0	-0.3	-1.5	-2.6	-3.4	-4.0	-4.3
		1600	1.6	0	-0.1	-1.9	-3.4	-4.6	-5.6	-6.2	-6.5
7.5	Center of mass	400	1.7	0	0	0	0	0	0	0	0
		800	3.6	1.3	0	0	0	0	0	0	0
		1200	4.0	1.6	0	0	0	-0.1	-0.9	-1.5	-1.8
		1600	4.1	1.5	0	0	-0.9	-2.1	-3.1	-3.7	-4.0
7.5	Front edge	400	5.9	4.4	3.0	1.7	0.6	0	0	0	0
		800	5.7	4.0	2.4	1.0	0	0	0	0	0
		1200	5.4	3.4	1.5	0	0	0	0	0	0
		1600	5.1	2.9	0.7	0	0	0	-0.9	-1.6	-1.9
8.75	Center of mass	400	3.0	0.2	0	0	0	0	0	0	0
		800	4.9	2.5	0.4	0	0	0	0	0	0
		1200	5.3	2.8	0.5	0	0	0	0	-0.3	-0.6
		1600	5.3	2.7	0.3	0	0	-0.9	-1.8	-2.5	-2.8
10.0	Center of mass	400	4.2	1.4	0	0	0	0	0	0	0
		800	6.1	3.8	1.6	0	0	0	0	0	0
		1200	6.5	4.0	1.8	0	0	0	0	0	0
		1600	6.6	4.0	1.6	0	0	0	-0.6	-1.2	-1.5

angle B = atn (y2/x) (4)

lead angle (degrees) = angle B - (90 degrees - gun angle) (5)

lead angle (mils) = lead angle (degrees) X (6400 mils/360 degrees) (6)

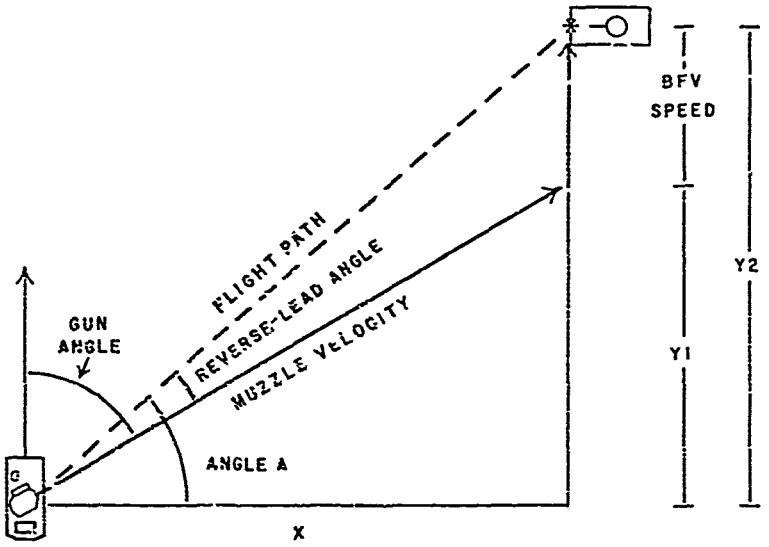

Figure 5. Illustration of the mathematical model used to calculate reverse lead when firing over the side of a moving vehicle.

As indicated by this mathematical model, the angular deviation of the projectile produced by vehicular movement is assumed to occur when the projectile leaves the gun barrel. This assumption was provided by the Ballistics Research Laboratory.

Findings

AP ammunition. The predicted reverse-lead requirements for a BFV are presented in Table 3. The gunnery manual (FM 23-1, 1983; 1986) does not specify vehicle speed in gunnery qualification tables so a typical BFV speed was arbitrarily selected to be 32 km/hr or 20 miles/hr. A 6.7-mil reverse lead is required at this speed when AP ammunition is fired from a gun oriented directly over the side of the BFV (90-degree gun angle). Firing at about 45 degrees in relation to the direction of vehicle movement requires a predicted reverse-lead of about 5 mils.

HE ammunition. Predicted reverse-lead requirements for HE ammunition also are presented in Table 3. Reverse-lead requirement for a vehicle traveling 32 km/hr with a 90-degree barrel orientation was 8.2 mils. Firing at the same speed with a 45-degree barrel orientation results in a reverse-lead requirement of less than 6 mils. Comparison of required reverse lead for AP and HE ammunition indicates only slight differences.

Table 3

Predicted Amount of Reverse Lead

BFV speed (km/hr)	Angle (degrees) of gun relative to direction of movement								
	10	20	30	40	50	60	70	80	90
	AP ammunition								
8	0.3	0.6	0.8	1.1	1.3	1.5	1.6	1.7	1.7
16	0.6	1.1	1.7	2.2	2.6	2.9	3.2	3.3	3.4
24	0.9	1.7	2.5	3.2	3.9	4.4	4.7	5.0	5.0
32	1.2	2.3	3.3	4.3	5.1	5.8	6.3	6.6	6.7
40	1.4	2.9	4.2	5.4	6.4	7.3	7.9	8.3	8.4
48	1.7	3.4	5.0	6.4	7.7	8.7	9.5	9.9	10.1
	HE ammunition								
8	0.4	0.7	1.0	1.3	1.6	1.8	1.9	2.0	2.1
16	0.7	1.4	2.1	2.6	3.1	3.6	3.9	4.1	4.1
24	1.1	2.1	3.1	3.9	4.7	5.3	5.8	6.1	6.2
32	1.4	2.8	4.1	5.3	6.3	7.1	7.7	8.1	8.2
40	1.8	3.5	5.1	6.6	7.8	8.9	9.6	10.1	10.3
48	2.1	4.2	6.1	7.9	9.4	10.6	11.6	12.1	12.3

Discussion and Conclusions

In a modern, mechanized conflict, the lethality and surviveability of the BFV will depend greatly on the capability to engage moving targets effectively and efficiently and to fire while on the move. The objective of this research was to develop a minimum number of aiming rules that optimize target hit capabilities, that are easy to learn, and that can be applied under combat conditions.

Engagement of Moving Targets from a Stationary BFV

For moving target engagements, the current analysis determined the amount of lead that would be required when the 25-mm is used under a wide range of target conditions (target speeds from 8 to 48 km/hr, ranges from 200 through 3000 meters, and angles of approach from 10 through 90 degrees). Target speed is difficult for gunners to estimate so efforts were made to develop lead rules that would be effective on targets traveling at the predicted average speed of a mechanized vehicle (20 miles/hour, FM 23-1, 1983).

Candidate aiming rules were developed based on the lead-requirement analysis and the design of the ISU gun reticle. The predicted hit capabilities of each lead rule were calculated for target angles classified as frontal and flank. Selection of the optimal lead rule(s) was based on considerations of hit capabilities for flank angles (25 degrees or greater) of the target.

Analysis indicates that lead rules recommended in the gunnery manual (FM 23-1, 1986) underestimate the lead required on moving targets. The AP lead rule specified in the BFV Gunnery manual (FM 23-1, 1986) is 2.5 mils from center-of-mass. If this rule is used, rounds will hit behind the target for ranges as short as 1000 meters for target angles as low as 60 degrees.

As a result of the current analysis, the recommended AP lead rule for moving target engagements is 5 mils from center-of-mass. The rule is called GAP LEAD because the target is centered in the gap of the lead lines on the reticle (see Figure 6). This rule provided hit capabilities for flank target exposures (angles from 30 through 90 degrees) through 1600 meters.

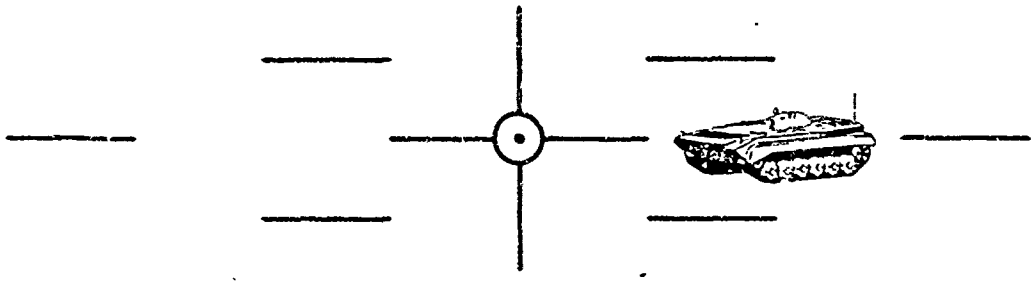

Figure 6. GAP LEAD applied on a flank angle of a moving BMP engaged with AP ammunition.

A separate lead rule is needed for HE ammunition because there is a much greater lead requirement for HE compared to AP ammunition (see Figure 2). The amount of lead that can be applied is limited by the deflection markings on the ISU reticle (they extend 10 mils to each side of the center dot). Target conditions that create more than a 10-mil lead requirement probably will lead to ineffective target engagement. For a target traveling 32 km/hr, a 10-mil lead is required for a 90-degree target angle at a range of 1600 meters so comparison of the relative hit capabilities of candidate lead rules was made for ranges up to that range.

The HE lead rule (5 mils from target center-of-mass) recommended in the gunnery manual (FM 23-1, 1986) had considerably lower hit capabilities than four other candidate lead rules: 7.5 mils from center-of-mass, 7.5 mils from front-edge, 8.75 mils from center-of-mass, and 10 mils from center-of-mass. Minor differences in the hit capabilities of these aiming rules depended on target range and angle. The aiming point of 8.75 mils from center-of-mass was selected based on considerations related to ease of use and training. The rule is called FAR LEAD because the far lead line is centered on the target (see Figure 7).

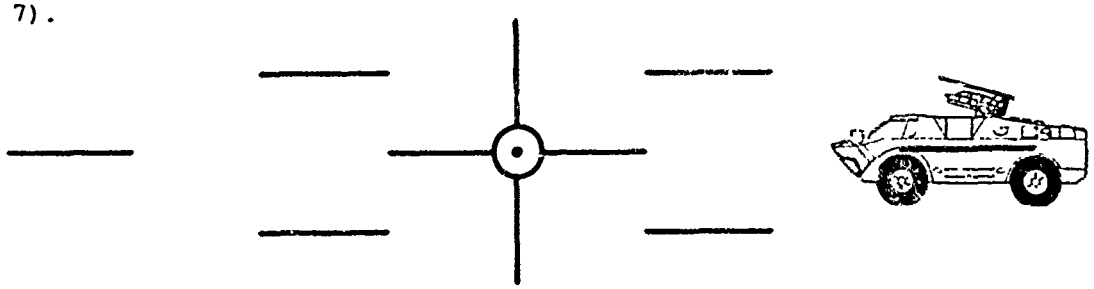

Figure 7. FAR LEAD applied on a flank angle of a moving BRDM engaged with HE or TP-T ammunition.

Engagement of Stationary Targets While Moving

The stabilization system of the BFV allows target engagement while moving. However, if the 25-mm gun is fired over the side of the vehicle, the gunner must aim behind the target (relative to direction of BFV movement) to compensate for the effect of vehicle movement on trajectory of the round. This aiming rule often is called reverse-lead.

When the gun is fired over the side of the vehicle, projectile displacement in mils is related to speed of the vehicle, muzzle velocity of the ammunition, and the angle of the gun barrel relative to movement of the vehicle. Analysis of varied BFV speeds (8 to 48 km/hr) and gun barrel orientation (10 to 90 degrees) indicates that both AP and HE ammunition had similar enough reverse-lead requirements to allow consideration of a single reverse-lead rule.

The recommended reverse-lead rule is 5 mils from center-of-mass (see Figure 8), the same aiming point on the ISU gun reticle used for the AP lead rule. This is the amount of lead required when firing AP ammunition at a 45-degree angle over the side of a vehicle traveling at 32 km/hr (see Table 3).

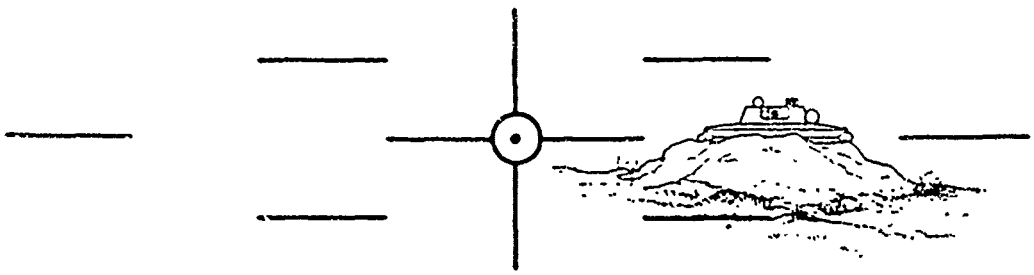

Figure 8. GAP LEAD applied when the Bradley fires over its left flank at a stationary BMP.

Summary

Mathematical analysis determined lead requirements for engaging moving vehicular targets with the 25-mm gun of the BFV. The predicted hit and miss capabilities of candidate lead rules were calculated for AP and HE ammunition. Analysis indicated that aiming rules recommended in the BFV Gunnery field manual (FM 23-1, 1986) underestimate actual requirements. Analysis indicated the following recommendations. Lead rules are applied on flank angles (i.e., the side of the target appears larger than the front) of moving targets. The optimal aiming rule for AP ammunition is 5 mils from target center-of-mass. This rule is called GAP LEAD because the target is centered in the gap of the lead lines on the reticle. The optimal HE lead rule is 8.75 mils from target center-of-mass. This is called FAR LEAD; the target is centered on the far lead line of the reticle. Additional analysis determined reverse-lead requirements for engaging stationary targets from a moving BFV. The recommended reverse-lead aiming rule for both AP and HE ammunition is 5 mils from target center-of-mass. The developed AP lead rule, HE lead rule, and reverse-lead rule will be included in the BFV Gunnery manual (FM 23-1).

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